Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 2.1

Core and Vessel Construction

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2.1 CORE AND VESSEL CONSTRUCTION

2.1.1 Introduction

The reactor vessel is designed to house and support the internals assemblies, fuel, control rod assemblies, and incore instrumentation. The vessel internals assemblies support the core and maintain control rod assembly alignment between fuel assemblies and control rod drive mechanisms. The assemblies also direct the flow of reactor coolant, provide gamma and neutron shielding, provide guides for incore instrumentation, and support the surveillance specimen assemblies.

2.1.2 Reactor Vessel

The reactor vessel is designed in accordance with ASME Boiler and Pressure Vessel Code, Section III, for class 1 vessels. The design considers all facets of plant operation for a 40-year life, including pre-operational testing, normal and abnormal operations, and accident conditions. Table 2.1-1 lists reactor vessel design data.

The reactor vessel consists of a cylindrical shell, a spherically dished bottom head, and a ring flange to which a removable closure head is bolted. The closure head is a spherically dished head welded to a ring flange, which mates with and is bolted to the vessel ring flange with large-diameter studs. Two concentric metallic O-rings provide the pressure integrity seal between the closure head and the vessel flange. High-pressure leakoff and drain taps are provided at the annulus between the two O-rings and outside the outer O-ring to provide leak detection and monitoring of the O-rings.

All internal surfaces of the vessel and closure head are weld-deposit clad with stainless steel or nickel-chrome-iron (Ni-Cr-Fe) for corrosion protection.

The reactor vessel is supported by integral pads at the underside of the four reactor inlet nozzles as shown on Figure 2.1-2. An attachment plate is bolted to each pad and bears on a lubrite spherical bearing. Side gibs restrain the lateral, vertical, and rotational movement of the reactor vessel. The gibs are shimmed and attached to the primary shield wall support plate by large screws. Thermal expansion is accommodated by radial sliding of the lubrite bearing.

All major reactor vessel penetrations are located above the top of the core to maintain a flooded core in the event of a postulated Loss Of Coolant Accident (LOCA). The bottom head of the vessel is penetrated by small nozzles for interfacing with the incore instrumentation guide tubes.

The reactor vessel has two outlet and four inlet nozzles. Two smaller core flooding nozzles serve as inlets for direct emergency cooling water injection (core flooding and low-pressure injection) and decay heat cooling water during normal shutdowns. The closure head is penetrated by flanged nozzles for attaching the control rod drive motors.

A ledge on the inside of the vessel flange supports the core support cylinder assembly. The closure head and closure studs provide a clamping force on the assembly.

Guide lugs are provided in the lower section of the reactor vessel to absorb the impact and limit the vertical movement of the core support cylinder assembly in the unlikely event of a complete circumferential severance of the core support cylinder below its support flange.

All interior surfaces of the vessel are accessible for inservice inspection. The vessel flange area and head can be inspected during refueling operations. The core support cylinder assembly can be removed from the reactor vessel. The straight shell portion of the reactor vessel is fabricated entirely from ring forgings. The reactor vessel shell material is protected from fast neutron flux and gamma heating effects by a series of water annuli and stainless steel barriers located between the core and the wall of the vessel.

2.1.3 Reactor Internals

The reactor internals comprise the following five major subassemblies:

1. core support cylinder assembly
2. core basket assembly
3. lower grid assembly
4. flow distributor assembly
5. plenum assembly

The general arrangement of these subassemblies is shown in Figures 2.1-3 and 2.1-4.

2.1.3.1 Core Support Cylinder Assembly

The Core Support Cylinder (CSC) shown in Figure 2.1-3 is a weldment consisting of forgings and rolled plates. The outward-facing upper flange is the main supporting flange for the core support cylinder assembly. Welded to the CSC upper shell are eight forged reinforcement rings for mounting eight vent valve assemblies. Below the forgings for the vent assemblies are the large forgings of the outlet nozzles. Differential thermal expansion between the CSC and the reactor vessel is such as to adequately limit bypass flow at the outlet forging/ vessel outlet nozzle interface sealing surfaces. These surfaces are machined to provide clearance for installation and removal of the core support cylinder assembly. The shell that extends downward from the nozzle forgings terminates in an inward-facing lower flange. This flange supports the core basket, lower grid, and flow distributor assemblies. The lower grid support forging is bolted to the CSC lower flange.

Pockets on the CSC lower flange are fitted with guide blocks which interface with the guide lugs on the inside of the reactor vessel. A gap exists between the guide blocks and lugs during all normal operating conditions.

Eight reactor internals vent valve assemblies (section 2.1.4) are attached to the reinforcement rings in the core support cylinder. In the event of a LOCA from an inlet line break, these assemblies vent steam from above the core so that emergency core coolant can be injected. Each vent valve assembly consists of a valve body and a disc. A positive pressure differential across the disc during normal operation ensures a positive seal.

Two surveillance specimen holder tube assemblies are mounted on the outside of the core support cylinder in the core region (Figure 2.1-16). The specimen holders house samples of reactor vessel base metal and weld metal. These samples are located in a thermal and neutron environment like that of the reactor vessel.

2.1.3.2 Core Basket Assembly

The core basket, shown in Figure 2.1-3, is comprised of a cylinder called the core barrel, horizontal former plates, and vertical baffle plates. The core basket assembly channels the reactor coolant through the core and attenuates the neutron flux and gamma rays impinging on the reactor vessel.

The formers and baffle plates form the inside configuration required for the core fuel assemblies. The baffle plates are bolted to eight levels of horizontal former plates, which are bolted to the core barrel. The bottom of the core barrel has a flange that is bolted to the lower grid assembly. All joints in the core basket assembly are bolted together.

Support pads attached to the inner surface of the core support cylinder at the upper end limit horizontal motion of the core basket assembly during upset and faulted conditions. There is clearance between the upper end of the core barrel and the support pads during normal operation.

2.1.3.3 Lower Grid Assembly

The lower grid assembly, shown in Figure 2.1-3, is attached to the lower end of the core basket assembly. The lower grid shell forging is welded to the top of the lower grid support forging. Support posts are welded to the lower grid support forging at selected interior locations. The lower grid top rib section, which supports the reactor core, is bolted to the lower grid shell forging and to the support posts. A perforated flow distributor plate is welded to the lower grid shell forging and to the support posts at their mid-height. This plate uniformly distributes the primary coolant entering the reactor core. A short cylinder, referred to as the lower-grid, lower-ring forging, is welded to the lower side of the lower grid support forging. The flow distributor assembly is bolted to this cylinder.

2.1.3.4 Flow Distributor Assembly

The flow distributor assembly, shown in Figure 2.1-3 and 2.1-4, consists of a flow distributor head, an incore guide support plate, and upper and lower sections of the incore instrument guide tubes. The flow distributor assembly aligns the incore neutron detectors and helps to control core flow distribution. The flow distributor head is a perforated, hemispherical cap. The incore guide support plate is a perforated, circular plate welded to the inside of the head. The lower sections of the guide tubes are welded to both the flow distributor head and the incore guide support plate. The upper end of each instrument guide tube attaches to the lower grid distributor plate for horizontal support. The lower sections of the guide tubes fit over the incore nozzles welded to the lower head of the reactor vessel. Clearance exists between the guide tubes and the incore nozzles during all operating conditions.

2.1.3.5 Plenum Assembly

The plenum assembly, shown in Figure 2.1-3, consists of a plenum cover, plenum cylinder, upper grid rib section, column weldments and brazements. The plenum assembly provides support for the upper ends of the fuel assemblies and guidance for the control rods, and directs reactor coolant flow from the fuel assemblies to the outlet nozzles.

The plenum cover is a composite circular plate consisting of inner disc and outer ring forgings. The periphery of the disc is machined into 36 spokes, which are the full height of the forging. The inner and outer forgings are welded together at each spoke. The plenum cover mates with the core support cylinder flange, and both are clamped together between the reactor vessel ledge and the closure head.

The plenum cylinder has a conical section at the lower end and is flanged at both ends. It contains a series of holes for passage of reactor coolant from the fuel assemblies. The plenum cylinder is bolted to the plenum cover and the upper grid rib section.

The upper grid rib section is a grillage-like structure formed by machining 205 square pockets (one for each fuel assembly) into a 3-inch-thick circular plate. Grid pads, which interface with and support the top of the fuel assemblies, are attached to the upper grid rib section.

The column weldments are long tubes bolted to the upper grid rib section and mechanically expanded into the plenum cover. Brazement assemblies, internal to the weldments, guide the control rods into the fuel assemblies. Each brazement is clamped into the upper end of the column weldment (at the plenum cover top surface) with a rod guide cap and is restrained at the lower end of the column weldment with three positioning (set) screws. The same support pads on the inner wall of the core support cylinder that limit horizontal motion of the core basket assembly during upset and faulted conditions perform this function for the plenum assembly. Clearance exists between the upper grid rib section and the core support cylinder during normal operation.

2.1.4 Internals Vent Valves

Internals vent valves (Figure 2.1-5) are included in Babcock and Wilcox reactor internals to provide a direct path to the break for steam venting after a loss-of-coolant accident resulting from a postulated cold leg rupture. The vent valves are required because the arrangement of the reactor coolant system can possibly inhibit the free venting of steam generated in the core after the system is depressurized, if significant quantities of coolant remain in the reactor inlet piping at the end of the blowdown period. Without free venting of the steam, a pressure differential could exist between the core region and the reactor vessel internals inlet annulus region where emergency coolant is injected. This pressure differential would inhibit flow into the core. To eliminate the problem, the vent valves are installed in the reactor internals to provide a flow path from the region above the core directly to the pipe rupture location. The flowpath provides for pressure equalization and permits emergency coolant water to reflood the core rapidly. Figures 2.1-3 and 2.1-16 show the locations of the internals vent valves.

Each valve assembly consists of a hinged disc, a valve body with sealing surfaces, a split retaining ring, and fasteners. Each valve is installed in a machined mounting ring welded in the wall of the core support cylinder.

All valve component parts, including the disc, are of "captured" design to eliminate the possibility of losing parts, and all fasteners have positive locking devices. The hinged disc includes an integral exercise lug for remote inspection of disc freedom during refueling.

In its natural position, the valve disc hangs closed. The valve seat is inclined 5 degrees from vertical to minimize bypass flow from the annulus to the upper plenum chamber assembly and to ensure a positive closing force at all times. The external side of the disc is contoured to absorb the impact load of the disc on the reactor vessel inside wall as a result of a loss-of-coolant cold leg break. The valve moves off its seat at a differential pressure of 0.125 psi, and a differential pressure of 0.26 psi is required to hold the valve at its full open (21-degree) position.

During refueling outages, after the reactor closure head and the internals plenum assembly have been removed, the vent valves are accessible for visual and mechanical inspection. A hook tool is provided to engage the valve disc exercise lugs for moving the valve discs manually to evaluate disc freedom. The vent valve assemblies can be removed and installed remotely with the aid of a vent valve handling tool, which has unlocking and operating features for the retaining rings.

2.1.5 Core Components

The core area of the reactor vessel and internals contains the following components:

1. fuel rod assemblies
2. fuel assemblies
3. control rod assemblies
4. axial power shaping rod assemblies
5. burnable poison rod assemblies
6. orifice rod assemblies
7. neutron source rods

The subsequent sections describe these components in detail.

2.1.5.1 Fuel Rod Assembly

Each fuel rod consists of fuel pellets, cladding, fuel support components, and welded end caps (Figure 2.1-6).

1. Fuel Pellets

   The fuel is in the form of sintered pellets of enriched uranium dioxide. The pellets are manufactured by cold pressing the enriched uranium dixoide powder into cylinders with dished ends and chamfered edges. This pellet geometry accommodates differential thermal expansion of the pellet. The hottest part of the pellet during operations is at the center of the pellet; this causes greater expansion to occur at the centers of the pellet ends. Once pressed, the pellets are then sintered to obtain the desired density and moisture content. After sintering is completed, the pellets are ground to the required dimensions. The pellets, along with other fuel rod components, are clad in Zircaloy-4 tubing.

2. Fuel Support Components

   Spring spacers are located above and below the pellet stack in each fuel rod. The springs are designed to accommodate thermal expansion of the fuel column. The lower spring is stiffer than the upper spring, so that most of the expansion is accommodated by the upper spring. In the event a pellet becomes wedged in the fuel rod, part of the expansion of the pellet stack can be accommodated by the lower spring. This feature helps to minimize stress in the fuel cladding.

Zircaloy spacers, located between the springs and the fuel, provide thermal insulation and separation.

Fuel fission gas release is contained within the pellet voids, the pellet-cladding gap, and the fuel rod end spacer voids. The rods are internally pressurized with helium to approximately 400 psi; the pressurized helium reduces the differential pressure across the cladding and provides improved heat transfer within the rods. The fuel, along with the other fuel rod components, is clad in Zircaloy-4 tubing and sealed with Zircaloy end caps. These end caps are welded to the fuel rod.

2.1.5.2 Fuel Assembly

The Mark C fuel assembly is a 17-fuel-pin-by-17-fuel-pin (17 x 17) design with an active length of approximately 12 ft. (Figure 2.1-7). There are 264 fuel rods, with one instrument tube position and 24 control rod positions in each fuel assembly. Eight spacer grids, seven spacer sleeves, and two end fittings form a structural cage to arrange the fuel rods and control rod guide tubes in the 17 x 17 array. The critical dimensions and mechanical parameters are given in Table 2.1-2. The guide tubes are attached to the upper and lower end fittings. Sufficient clearance between the fuel rods and the end fittings allows for axial length changes of the fuel rods. The following sections describe the mechanical design of the fuel assembly. Refer to Figure 2.1-8, fuel assembly schematic.

1. Upper End Fitting

   The upper end fitting positions the fuel assembly in the upper grid rib section and provides a means for coupling the fuel-handling equipment. Included in the upper end fitting are holddown springs and a spider that provides a positive holddown force to oppose hydraulic forces caused by coolant flow. The upper end fitting is designed with penetrations for the control rod guide tubes and for channeling flow directly out of the upper end of the fuel assembly.

2. Lower End Fitting

   The lower end fitting positions the fuel assembly in the lower grid top rib section. The lower end fitting grid provides a support surface for the bottom end of the fuel rods. Control rod guide tubes are attached to the lower end fitting. In addition, penetrations are provided for the instrumentation tube and to permit coolant flow into the bottom of the fuel assembly.

3. Spacer Grids

   Spacer grids are fitted together in an "egg-crate" fashion, which forms the 17 x 17 lattice. The square cells formed by the lattice provide support for the fuel rods in two perpendicular directions through contact points on each cell wall. The contacts are in the form of protruding dimples. On each of the two end spacer grids, the outer strip is extended and mechanically attached to the respective end fitting.

4. Guide Tubes

The guide tubes are constructed of Zircaloy-4 and provide a guidance envelope for the control rods as they are moved in or out of the fuel assembly during operation. In addition, they provide the same function for other types of fuel assembly inserts (e.g., burnable poison rod assembly). The guide tubes provide the structural continuity for the fuel assembly. At each end of the guide tube are threaded sleeves, which secure the guide tube to each end fitting by welded nuts.

5. Instrumentation Tube

The instrumentation tube is also constructed of Zircaloy-4 and acts as a channel to guide and contain an incore instrumentation assembly (chapter 7.0). The tube is located at the center of the fuel assembly and is axially retained at the lower end fitting.

6. Spacer Sleeves

The spacer sleeves fit around the instrument tube between the spacer grids and restrict axial movement of the spacer grids.

2.1.5.3 Control Rod Assembly

Each control rod assembly has 24 control rods, a stainless steel spider, and a female coupling (Figure 2.1-9). Each control rod is attached to the spider by a nut threaded to the upper end of the rod. All the nuts are welded after assembly. The control rod drive mechanism (chapter 6.1) is coupled to the control rod assembly by a bayonet connection. The control rod assembly has adequate flexibility and clearance to permit freedom of motion within the full length of the fuel assembly guide tubes. At the fully withdrawn position of the control rod drive mechanism, the lower end of the control rod assembly remains within the fuel assembly guide tubes.

The absorber material used in the control rods is boron carbide. It is clad with type 304 stainless steel tubing. Stainless steel end caps are welded to the tubing to ensure a watertight boundary for the absorber material. In addition to providing corrosion protection, the stainless steel provides structural strength for the control rods. Control rod assembly data are presented in Table 2.1-3. The locations of the control rods are shown in Figure 2.1-13.

2.1.5.4 Axial Power Shaping Rod Assembly

The axial power shaping rod assembly (APSRA) is similar to the control rod assembly (CRA) except for a shorter poison section (Figure 2.1-10). The female couplings of the APSRA and CRA have slight dimensional differences to ensure that each type of rod can only be coupled to the correct type of drive mechanism.

Each axial power shaping rod (APSR) has a section of neutron-absorbing material, which is an alloy of silver-indium-cadmium, and is clad with type 304 stainless steel tubing. This tubing provides the structural strength for the APSRAs and prevents corrosion of the absorber material. The absorber section is sealed by welding an internal plug and end plug to the cladding. The section of tubing above the absorber is vented to the coolant. Thus, the pressure differential across the tube wall is negligible. Data on the APSRAs are presented in Table 2.1-4.

There are some B&W plants that have changed to a new type of APSR, referred to as "gray" APSRs. The poison used in these rods is Inconel 600, and the active poison length is 63 inches.

2.1.5.5 Burnable Poison Rod Assembly

There are 109 burnable poison rod assemblies (BPRAs) loaded in the core. Each burnable poison rod assembly (Figure 2.1-11) has 24 burnable poison rods, a stainless steel spider, and a holddown attachment. The holddown attachment and the 24 rods are attached to the spider. The BPRA is inserted into the fuel assembly guide tubes through the upper end fitting.

Each burnable poison rod has a section of sintered aluminum oxide - boron carbide (Al203 - B_4C) pellets which serve as burnable poison. The poison section is axially located by internal spacers, which are designed to permit differential axial expansion of the cladding and poison section. The burnable poison is clad with Zircaloy-4 tubing and Zircaloy-4 upper and lower end pieces. The end pieces are welded to the tubing to form a coolant barrier container for the absorber material. The Zircaloy-4 tubing is the structural member of each BPR.

2.1.5.6 Orifice Rod Assembly

The orifice rod assemblies limit bypass flow through empty fuel assembly guide tubes (Figure 2.1-12). The orifice rod assemblies are placed in fuel assemblies that are not occupied by some other control components. Each orifice rod assembly consists of 24 orifice rods. The orifice rods are 12 in. long and constructed of type 304 stainless steel.

2.1.5.7 Combination Neutron Source Rods

Combination neutron source rods (CNSRs) provide a source of neutrons to ensure a minimum indication on the nuclear instrumentation for initial startup and subsequent cycles. The reason for this is primarily a matter of safety. To control the reactor properly, the operator must have an indication of reactor power on the nuclear instrumentation at all times. With a source in the core, the neutron population is raised to a point where the instruments present a true picture of reactor conditions, even though the reactor may be completely shut down with all control rods inserted.

The source materials consist of both a primary and a secondary source. The primary source is californium-252, which spontaneously emits neutrons during initial core loading and startup.

After a certain time period, the primary source decays and is no longer able to provide a sufficient source of neutrons. The secondary source is a regenerative neutron source and is composed of antimony-beryllium.

$$ {}_{0}\gamma^{0} + {}_{4}Be^{9} \rightarrow 2\,{}_{2}\alpha^{4} + {}_{0}n^{1} $$

The above reaction shows that beryllium, after absorbing a gamma ray, will emit a source neutron. To make the beryllium work as a neutron source, a source of high-energy gamma rays is provided by the following antimony reaction:

$$ \begin{gathered} {}_{51}Sb^{123} + {}_{0}n^{1} \rightarrow {}_{51}Sb^{124} + {}_{0}\gamma^{0} \\ {}_{51}Sb^{124} \rightarrow {}_{52}Te^{124} + {}_{-1}\beta^{0} + {}_{0}\gamma^{0} \\ (60 - day\ half - life) \end{gathered} $$

The second gamma ray produced by the decay of antimony-124 is of sufficient energy to react with the beryllium to produce the source neutrons. Each CNSR is attached to the spider of an orifice rod assembly at the plant site just before initial fuel loading. The sources are located in the core adjacent to the source range excore detectors.

2.1.6 System Interrelationships

2.1.6.1 Core Loading

The reactor core is designed to operate at 3760 Mwt for 460 full-power days during the first fuel cycle and an average of 292 full-power days during subsequent fuel cycles. To be able to operate at full power for this time period, enough fuel must be added to the core to overcome all the negative reactivity effects. During the first fuel cycle, this amounts to 10^6 metric tons of uranium dioxide (UO_2). Section 2.1.5.2 discussed fuel assembly construction. Figure 2.1-14 shows the four fuel enrichments used and their locations in the core. Each fuel assembly is uniform in its enrichment.

The amount of fuel loading required produces a K_{eff} of 1.24 with a cold clean core. To overcome the excess reactivity in the core, a combination of soluble boron (approximately 1170 ppm) and burnable poison rods is used. The construction of the burnable poison rods is discussed in section 2.1.5.5. As with the fuel assemblies, the burnable poison rod assemblies are identically constructed, but with varying concentrations. Figure 2.1-15 shows the locations and concentrations used. Use of the burnable poison rod assemblies allows the soluble boron concentration to be lower, which prevents an excessively large positive moderator temperature coefficient.

2.1.6.2 Reactor Vessel and Bypass Flows

Reactor coolant enters the reactor vessel through the four inlet nozzles and flows downward between the core support cylinder assembly and the vessel wall. After reaching the bottom of the vessel, the coolant flows upward through the flow distributor assembly and lower grid and into the core. When the coolant exits the top of the core, it enters the plenum assembly. The coolant flows outward through holes in the plenum assembly and hot leg penetrations in the core support cylinder to the two outlet nozzles.

About 94.9% of the reactor coolant that enters the reactor vessel will flow through the core to remove energy generated in the fuel. The other 5.1% is not available to remove energy and is considered bypass flow. Most of this bypass is flow between the baffle plates and the core basket (2%), and the flow through the control rod guide tubes and instrument guide tubes (1.6%). The remainder of the bypass flow is the flow between the outer fuel assemblies and the baffle plates (0.8%), the flow directly from inlet to outlet nozzles due to seal leakage (0.5%), and vent valve seepage (0.2%).

2.1.7 Summary

The reactor vessel and internals are designed to house and support the core, control rod assemblies, and incore instrumentation. The reactor vessel is designed for a 40-year plant life and is an integral part of the primary system boundary. The reactor internals, which support and provide flowpaths through the core, consist of the following major subassemblies:

1. core support cylinder assembly
2. core basket assembly
3. lower grid assembly
4. flow distributor assembly
5. plenum assembly

The internals vent valves are important internal components which are necessary to ensure proper core flooding following a LOCA.

The reactor core contains the UO_2 fuel in the form of fuel rods, as well as control and support components that are inserted into the fuel assemblies. These include the following:

1. control rod assemblies
2. axial power shaping rod assemblies
3. burnable poison rod assemblies
4. orifice rod assemblies
5. combination neutron source assemblies

The reactor core contains sufficient excess reactivity to operate at full power (3760 Mwt) for a full fuel cycle. To ensure a manageable power distribution in the core area, the fuel and burnable poison rod assemblies are of varied enrichments and concentrations, which are distributed throughout the core to ensure proper power distribution.

TABLE 2.1-1
REACTOR VESSEL DESIGN DATA

Item	Data
Design pressure, psig	2500
Design temperature, °F	670
Overall height (vessel and closure head), ft.	43
Straight shell thickness, in. (minimum, without cladding)	9.125
Water volume (70 °F) (including core support assembly and fuel), ft^3	4791
Vessel flange inside diameters (ID), in.	182
Shell ID, in. (to cladding)	182
Inlet nozzle, quantity	4
Inlet nozzle ID, in.	28
Outlet nozzle, quantity	2
Outlet nozzle ID, in.	38
Core flooding nozzle, quantity	2
Core flooding nozzle ID, in. (ID of flow restrictor)	9
Reactor closure head studs, quantity	60
Reactor closure head studs (diameter), in.	7
Control rod and axial power shaping rod drive nozzles, quantity (maximum)	76
Control rod and axial power shaping rod drive nozzles (ID), in.	2.765
Incore instrumentation nozzles, quantity	62
Incore instrumentation nozzles (ID), in.	0.612

TABLE 2.1-2
FUEL ASSEMBLY COMPONENTS, MATERIALS, and DIMENSIONS

Item	Material	Dimensions, In.
Fuel Rod (264)		
Fuel	94% TD UO_2 sintered pellets	0.324 OD
Cladding	Zircaloy-4	0.379 OD × 0.332 ID
Fuel rod pitch	--	0.501
Active fuel length	--	143.0
Nominal fuel cladding gap (Beginning of Life)	--	0.008
Fuel Assembly		
Fuel assembly pitch	--	8.587
Overall dimensions	--	165.625 axial 8.536 × 8.536 lateral
Guide tube (24)	Zircaloy-4	0.465 OD × 0.430 ID
Instrumentation tube (1)	Zircaloy-4	0.420 OD × 0.390 ID
End fitting (2)	Stainless steel	--
Spacer grid (8)	Inconel-718	--
Spacer sleeves (7)	Zircaloy-4	0.480 OD × 0.438 ID

NOTE: OD = outside diameter, ID = inside diameter, TD = theoretical density

TABLE 2.1-3
CONTROL ROD ASSEMBLY DATA

Item	Data
Number	68
Control rod outside diameter, in.	0.377
Cladding thickness, in.	0.0335
Cladding material	Type 304 SS
End plug material	Type 304 SS
Poison material	B_4C
Poison section length, in.	139
Spider material	SS, grade CF3M
Female coupling material	Type 304 SS
Pellet OD, in.	0.285

TABLE 2.1-4
AXIAL POWER SHAPING ROD (APSR) ASSEMBLY DATA

Item	Data
Number	8
APSR outside diameter, in.	0.390
Cladding thickness, in.	0.019
Cladding material	Type 304 SS
Plug material	Type 304 SS
Poison material	80% Ag, 15% In , 5% Cd
Poison section length, in.	36
Spider material	SS, grade CF3M
Female coupling material	Type 304 SS

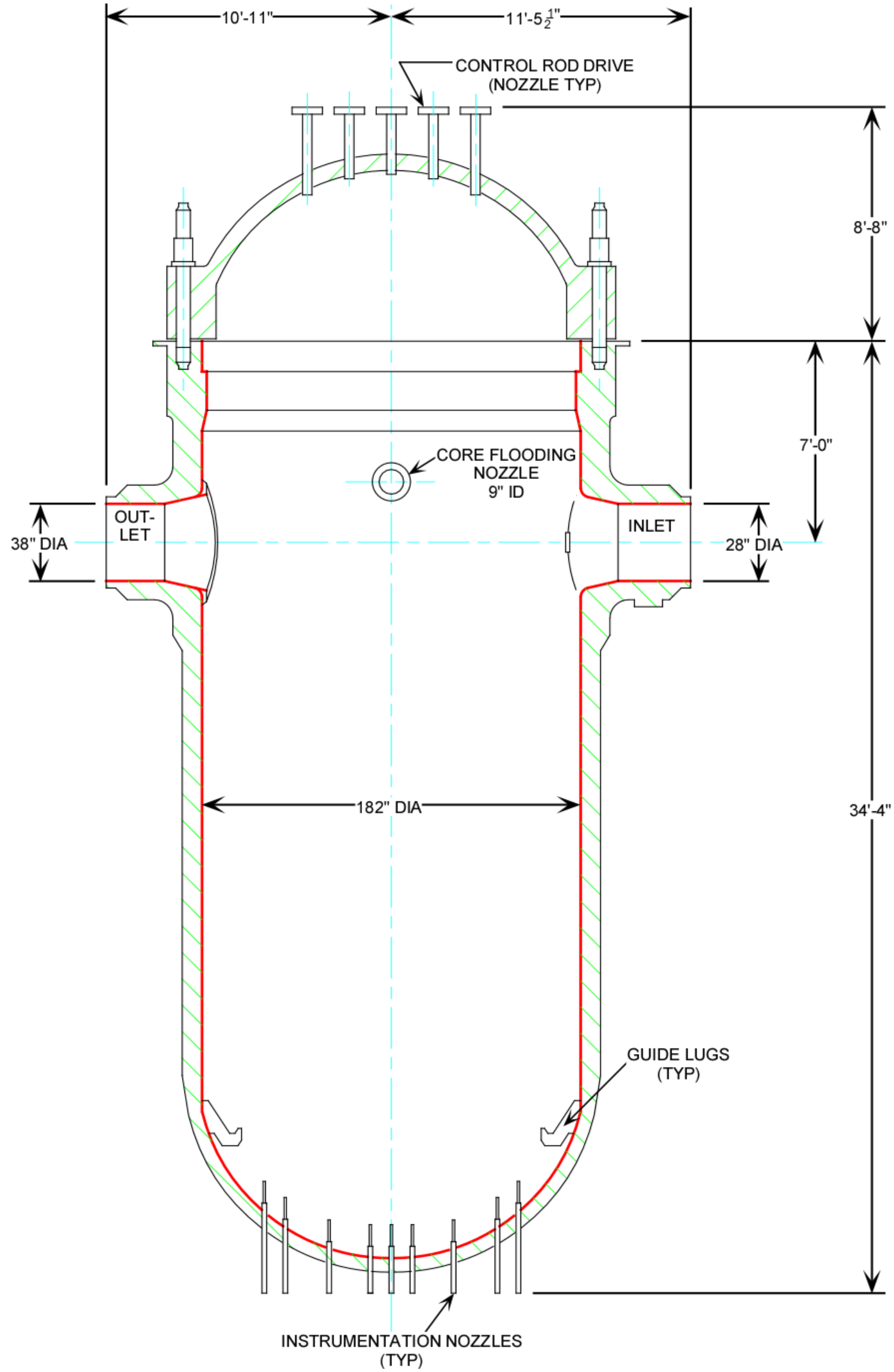

Figure 2.1-1 Reactor Vessel Cross Section

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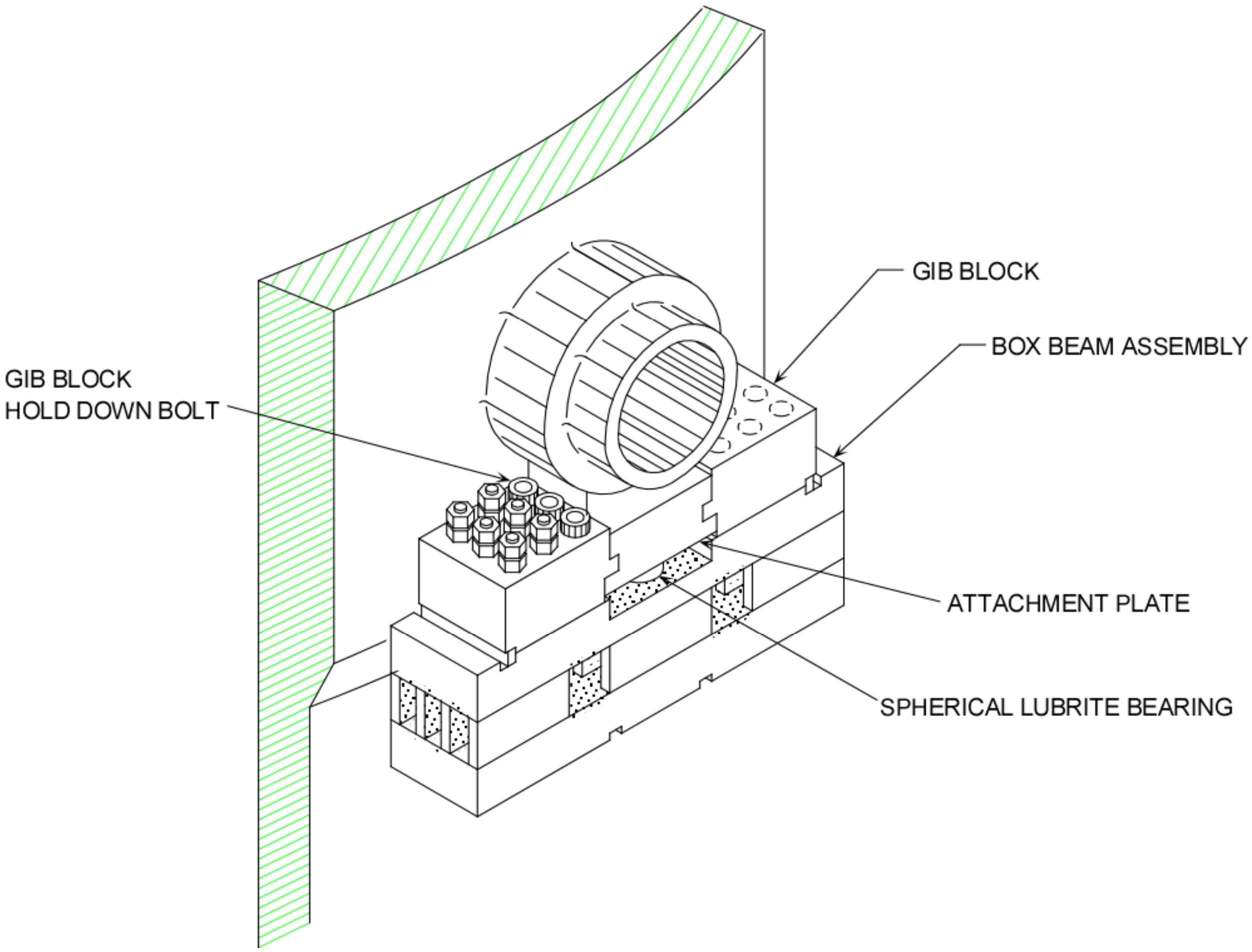

Figure 2.1-2 Reactor Vessel Support System

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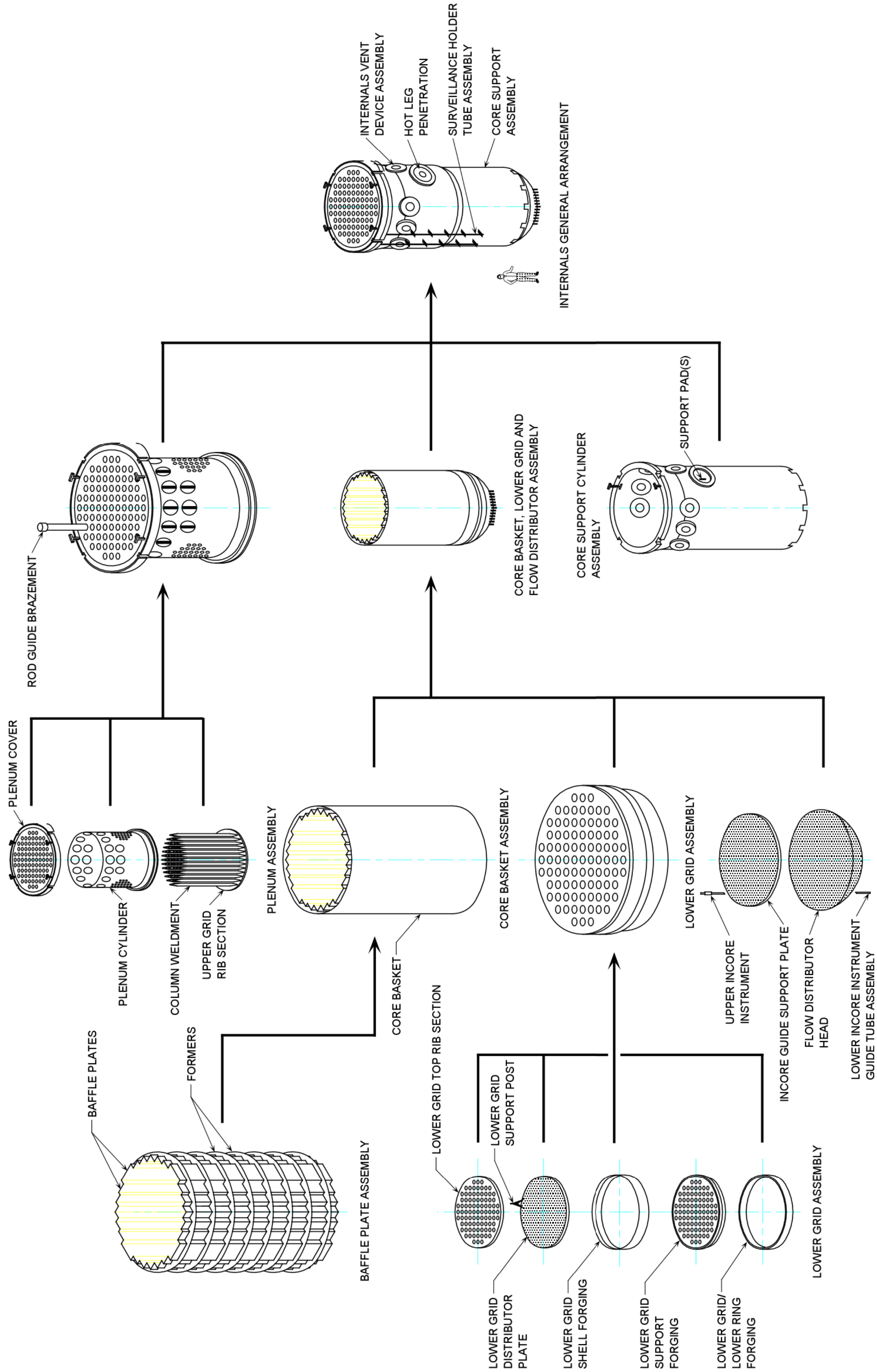

Figure 2.1-3 Reactor Vessel Internals Arrangement

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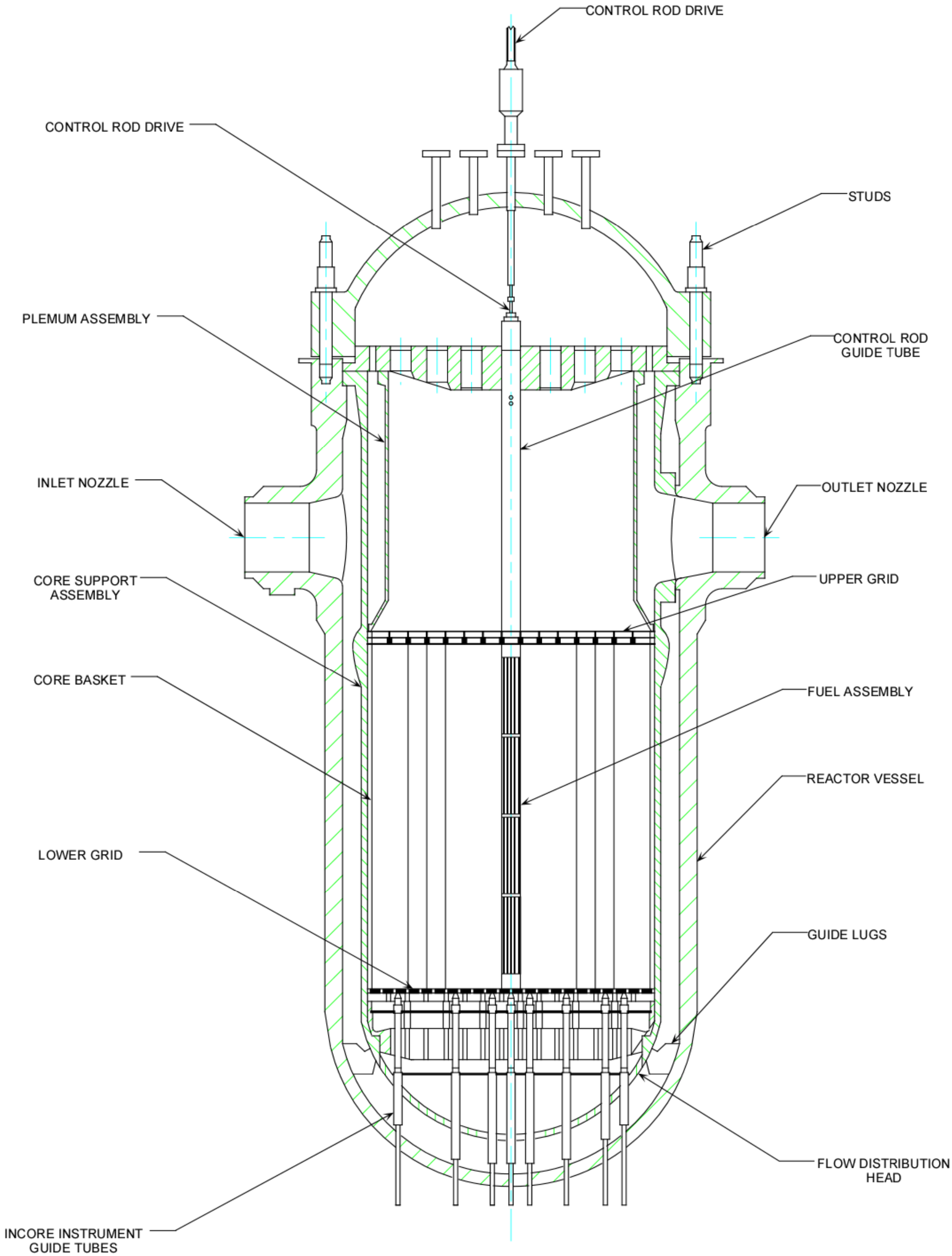

Figure 2.1-4 Reactor Vessel and Internals

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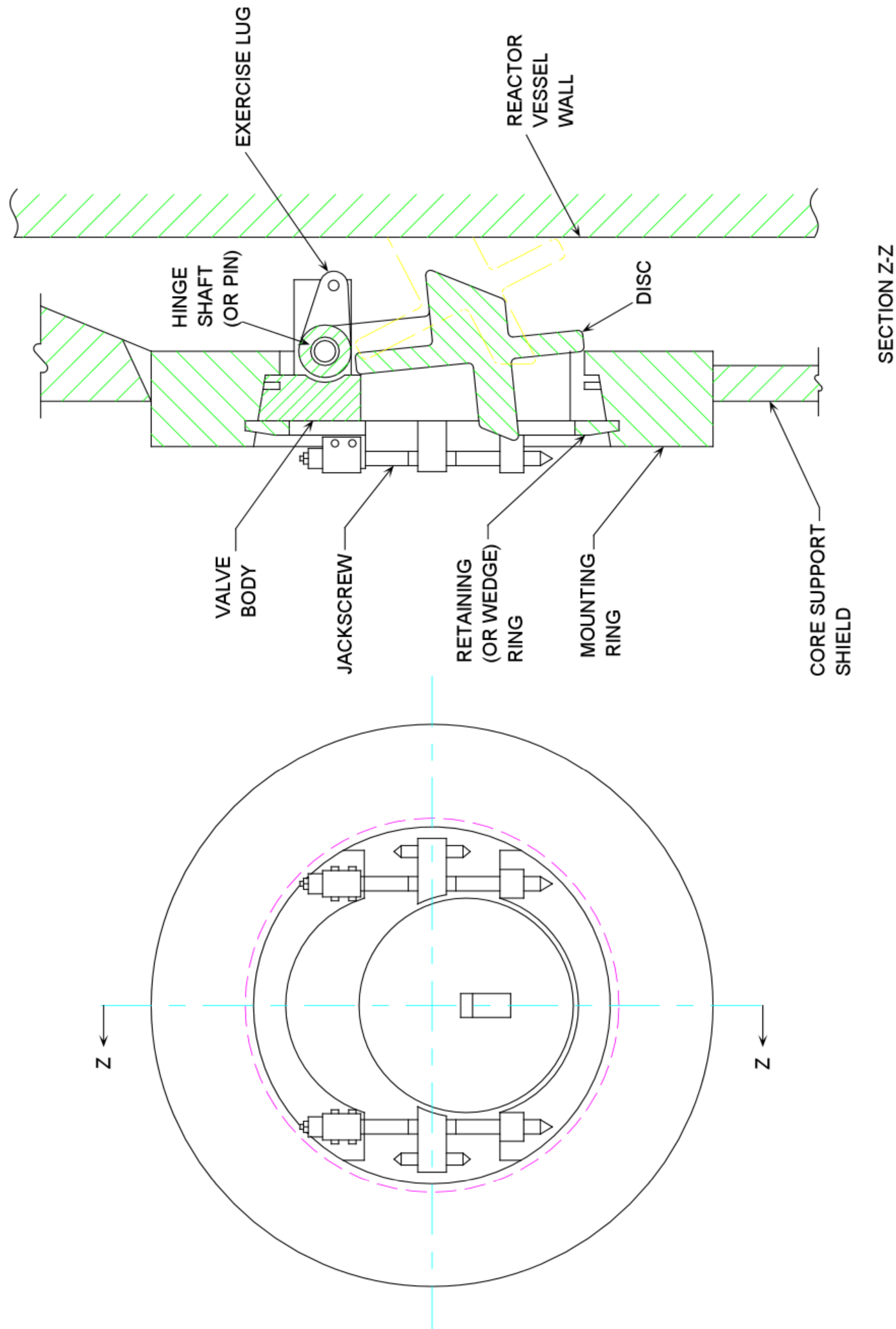

Figure 2.1-5 Vent Valve Arrangement

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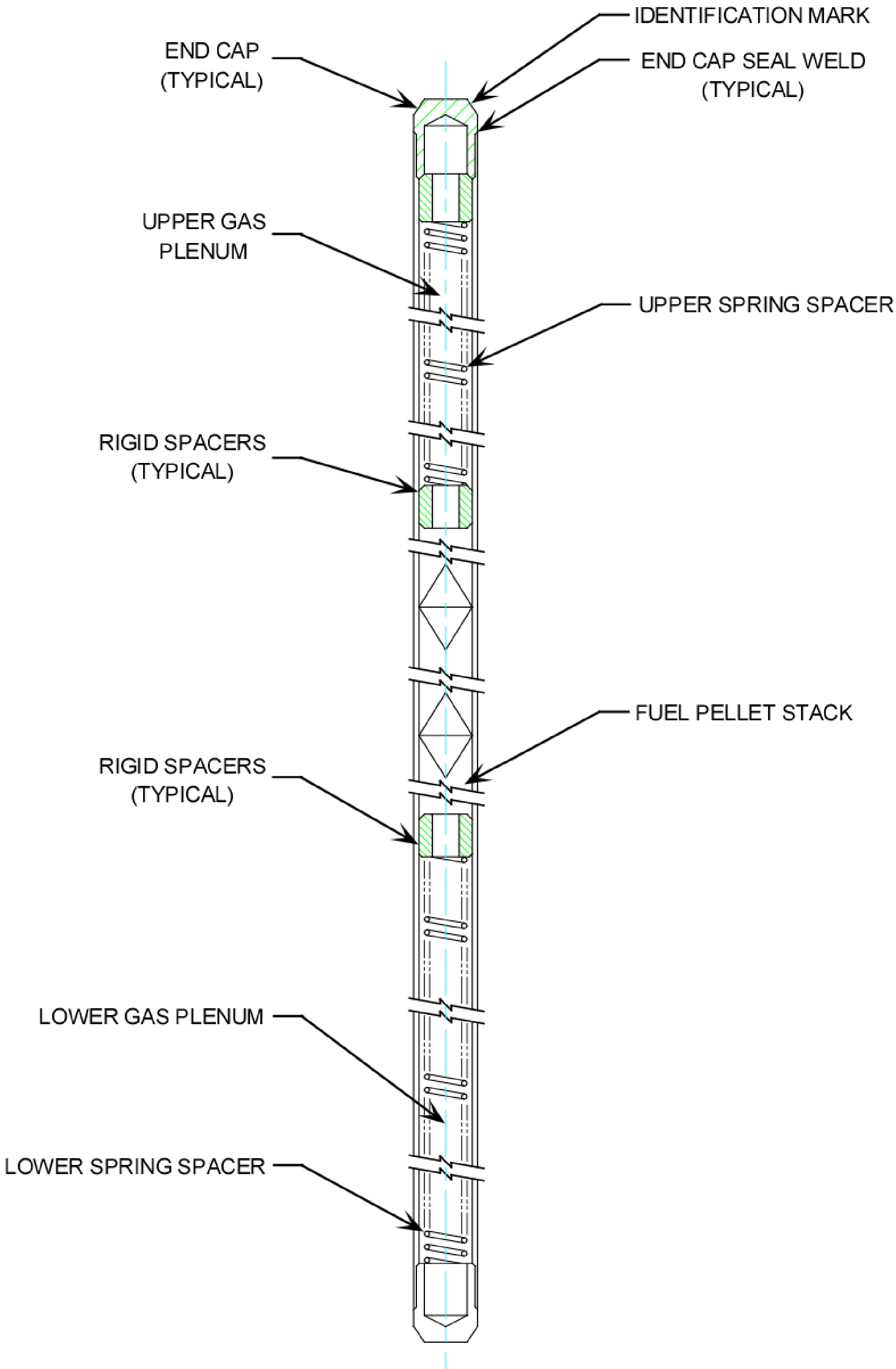

Figure 2.1-6 Fuel Rod Assembly

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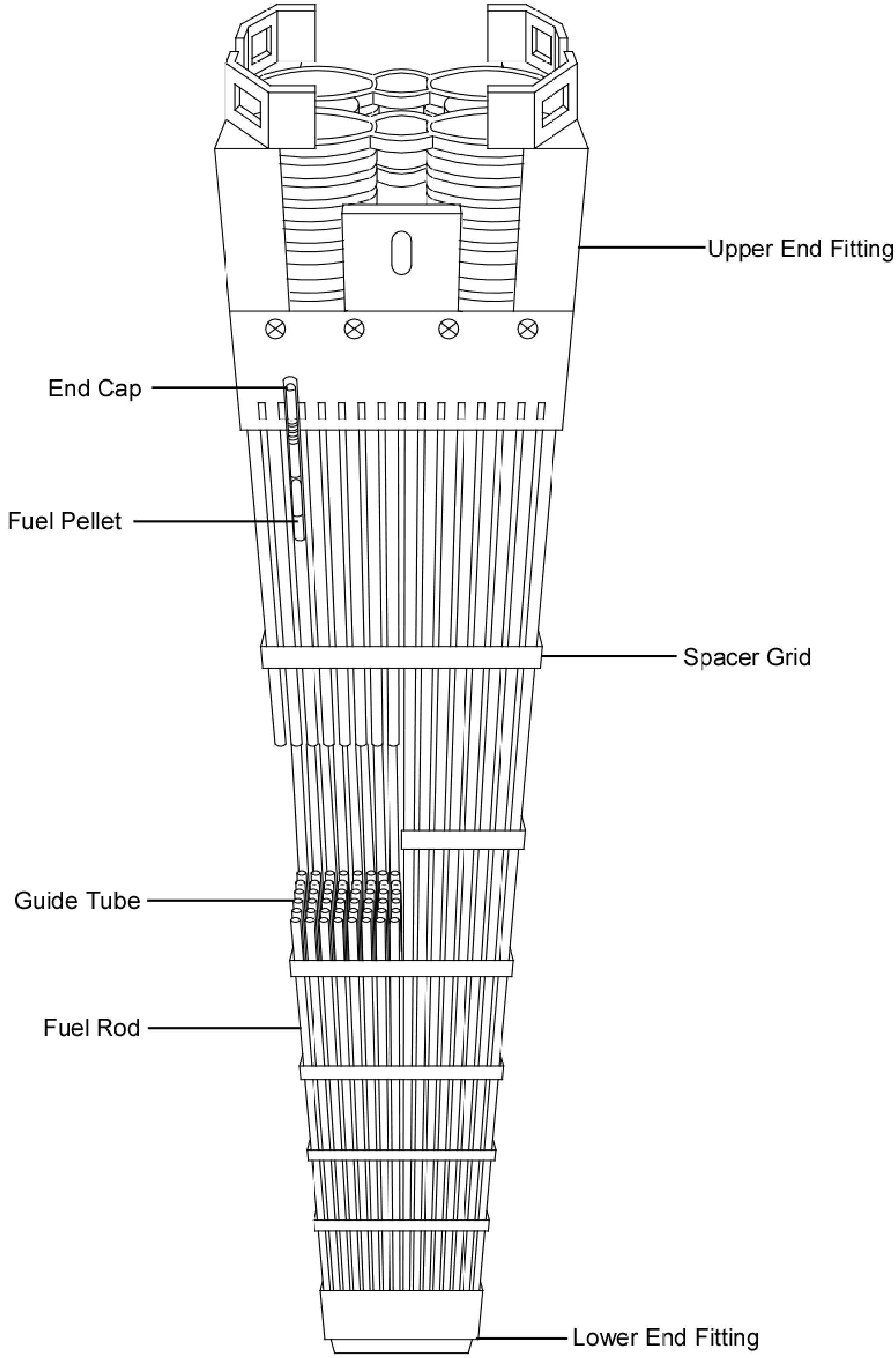

Figure 2.1-7 Fuel Assembly

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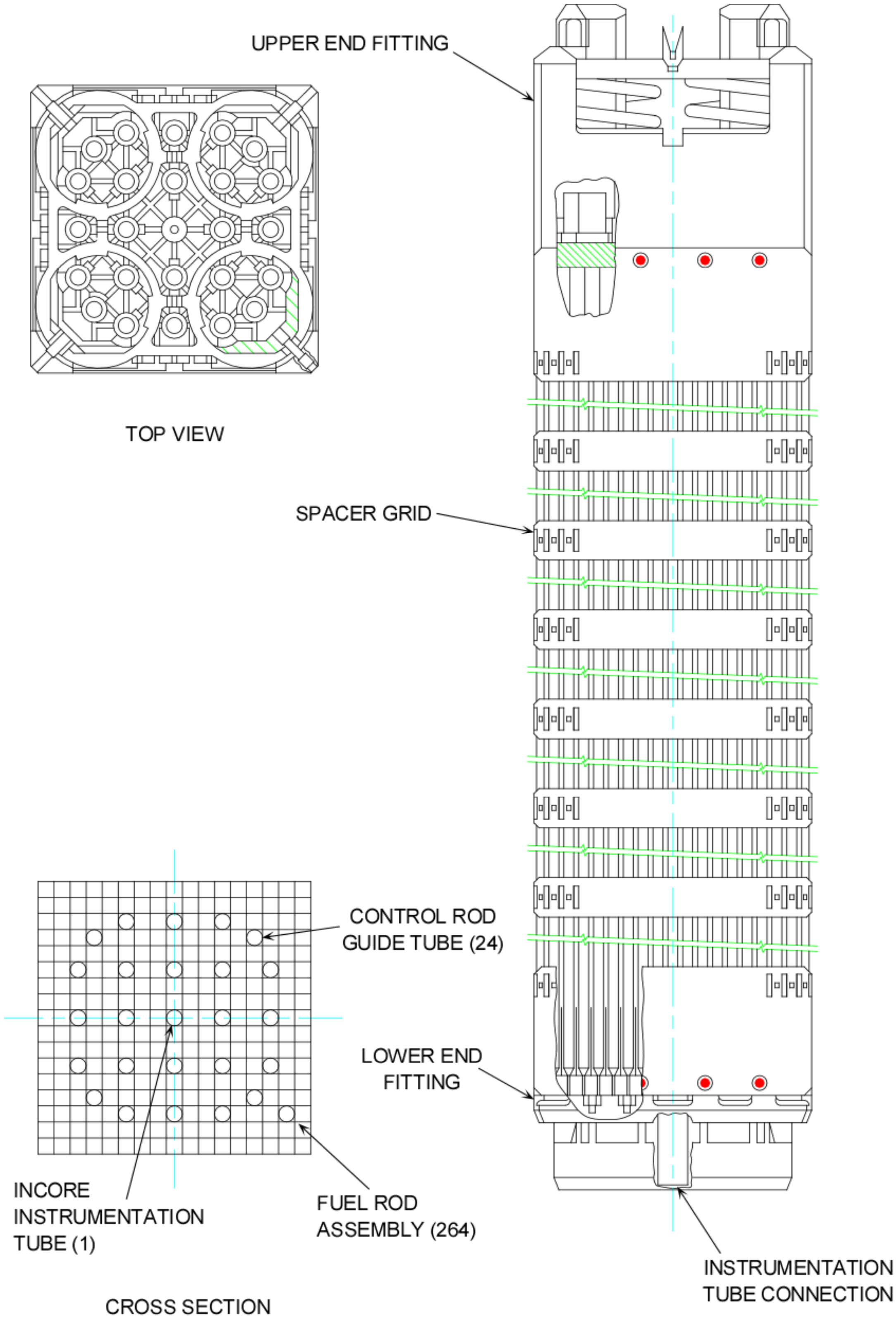

Figure 2.1-8 Mark C Fuel Assembly

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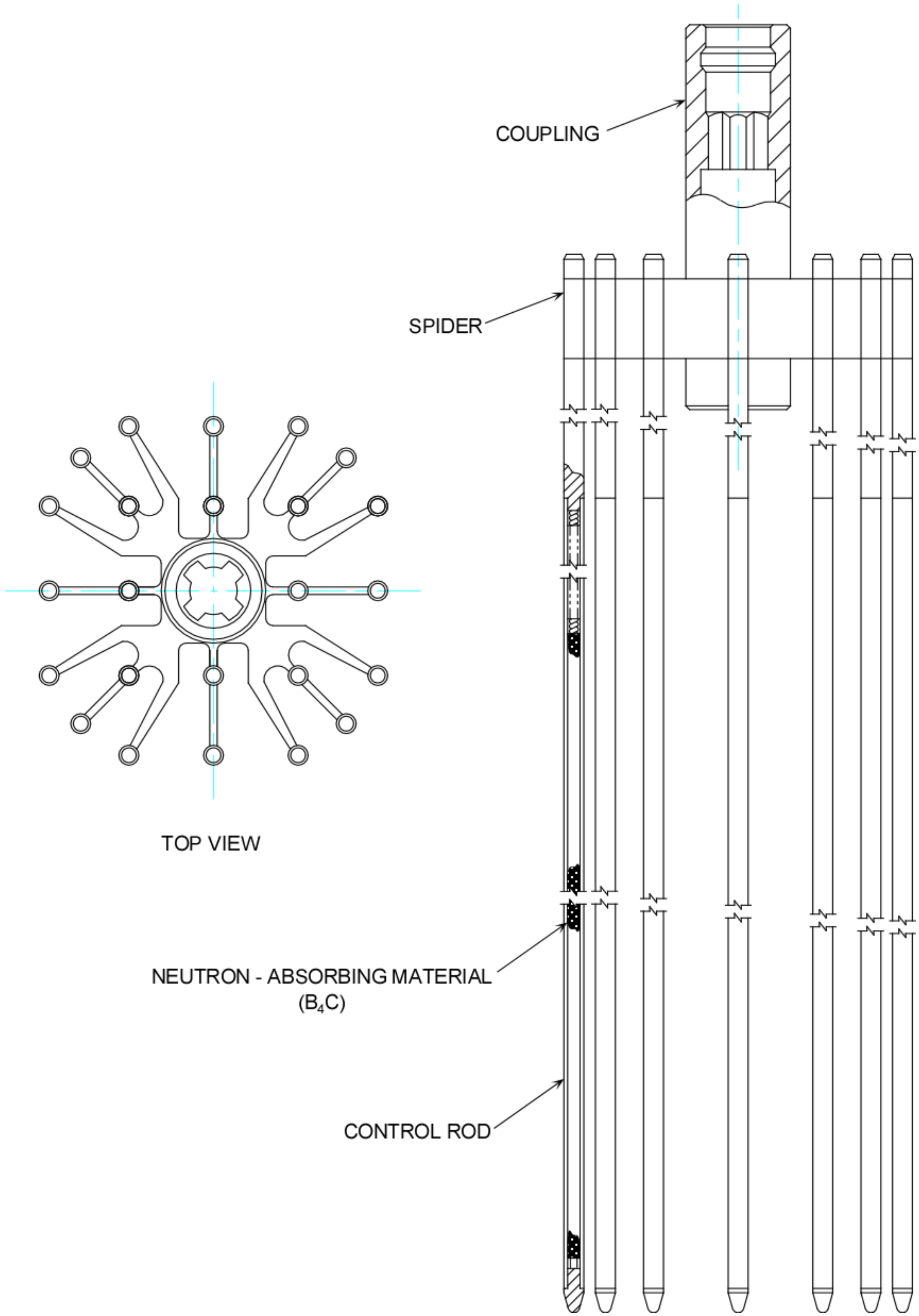

Figure 2.1-9 Control Rod Assembly

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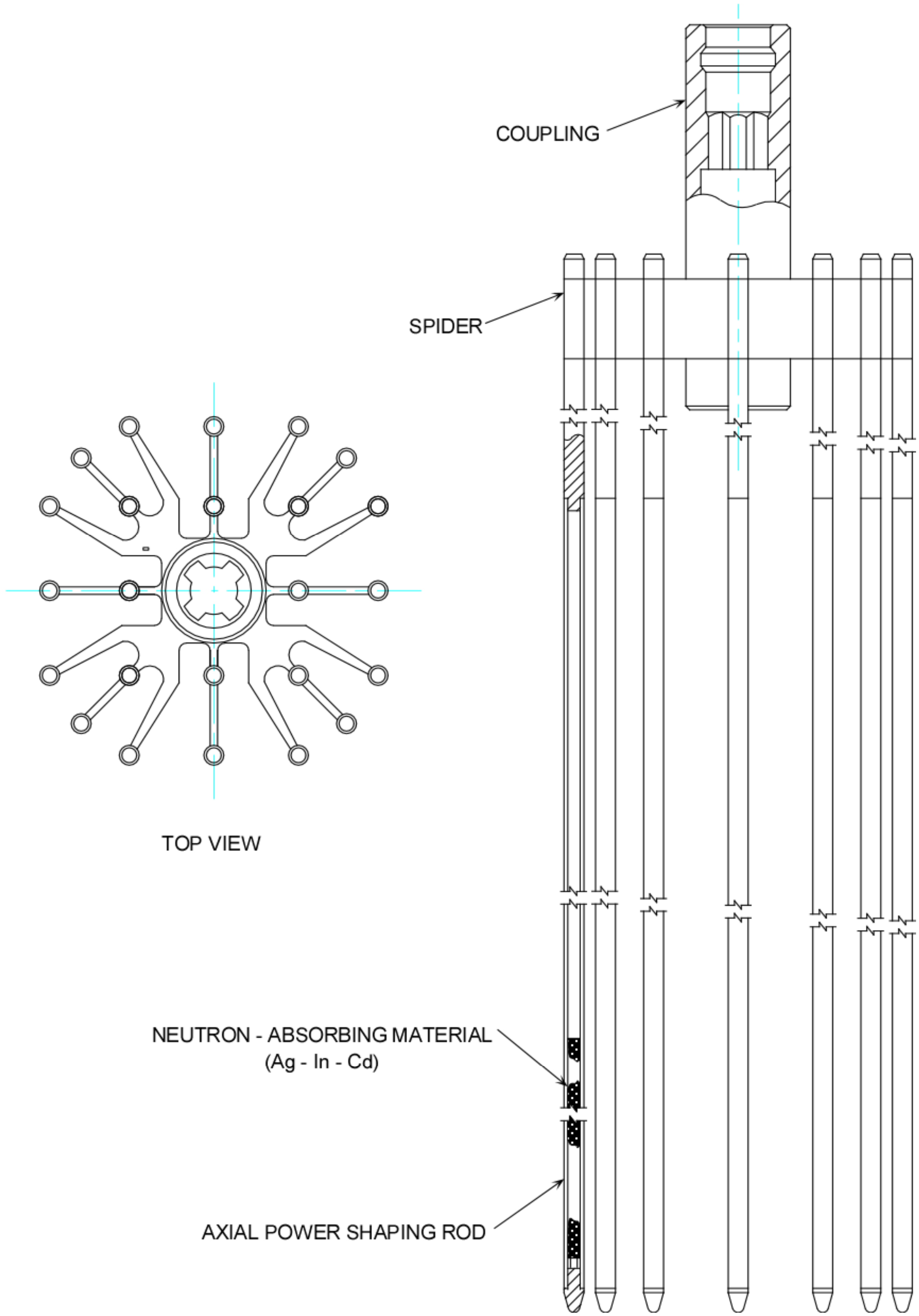

Figure 2.1-10 Axial Power Shaping Rod Assembly

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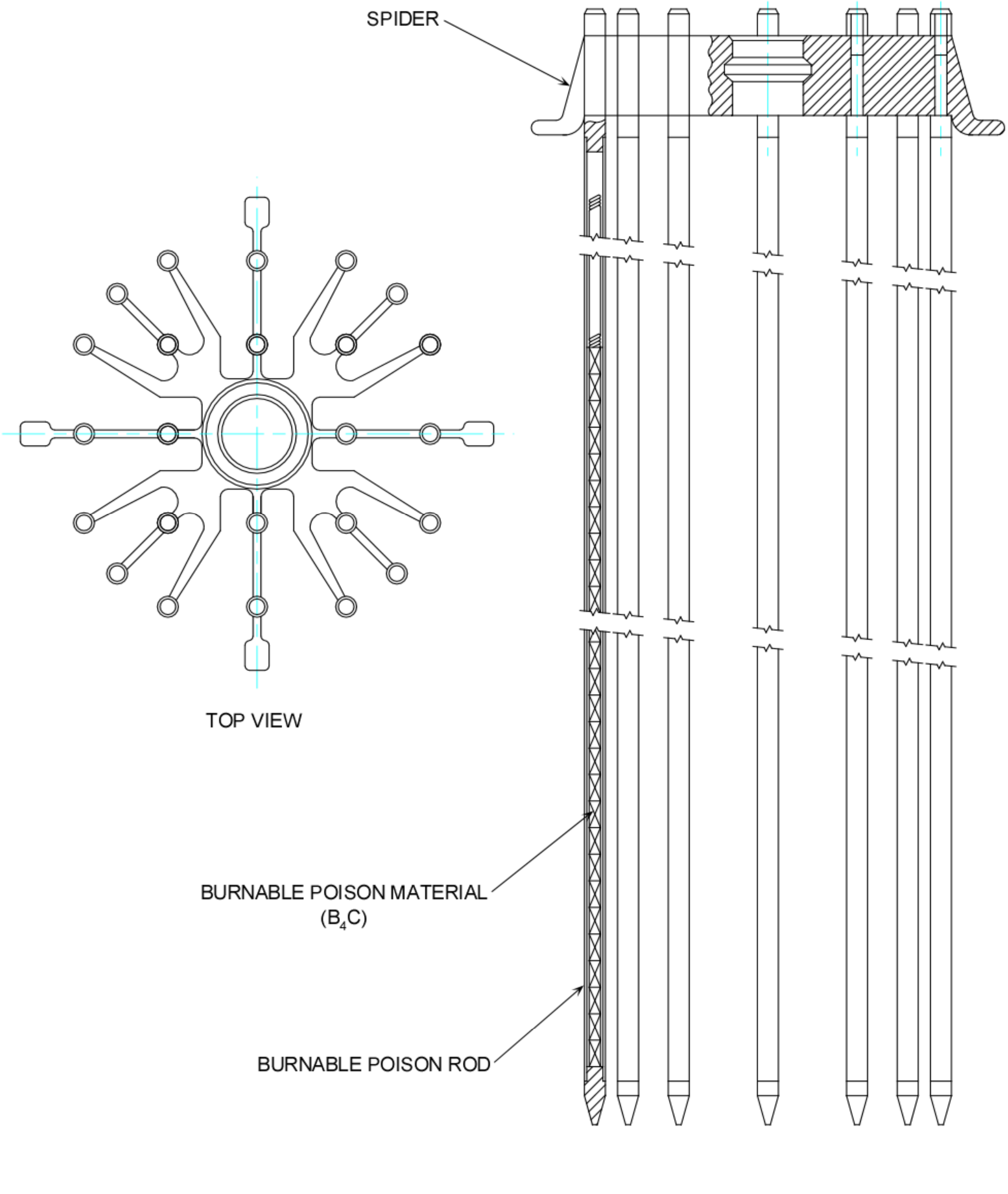

Figure 2.1-11 Burnable Poison Rod Assembly

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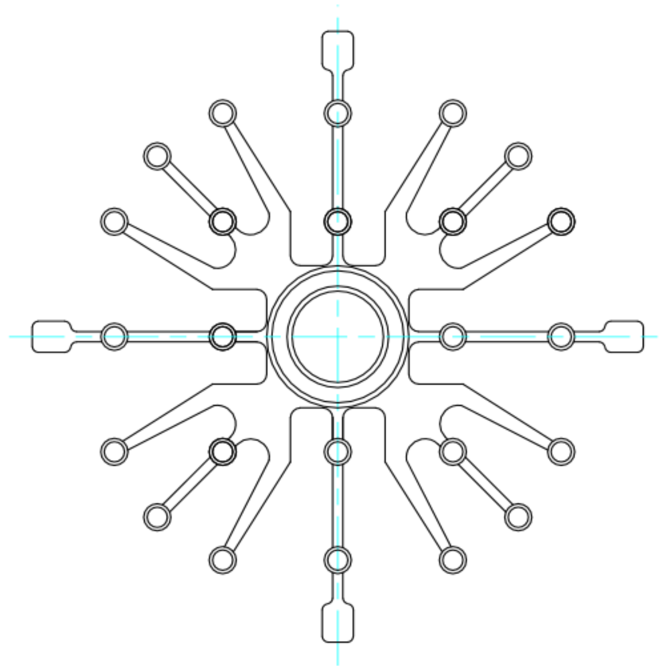

TOP VIEW

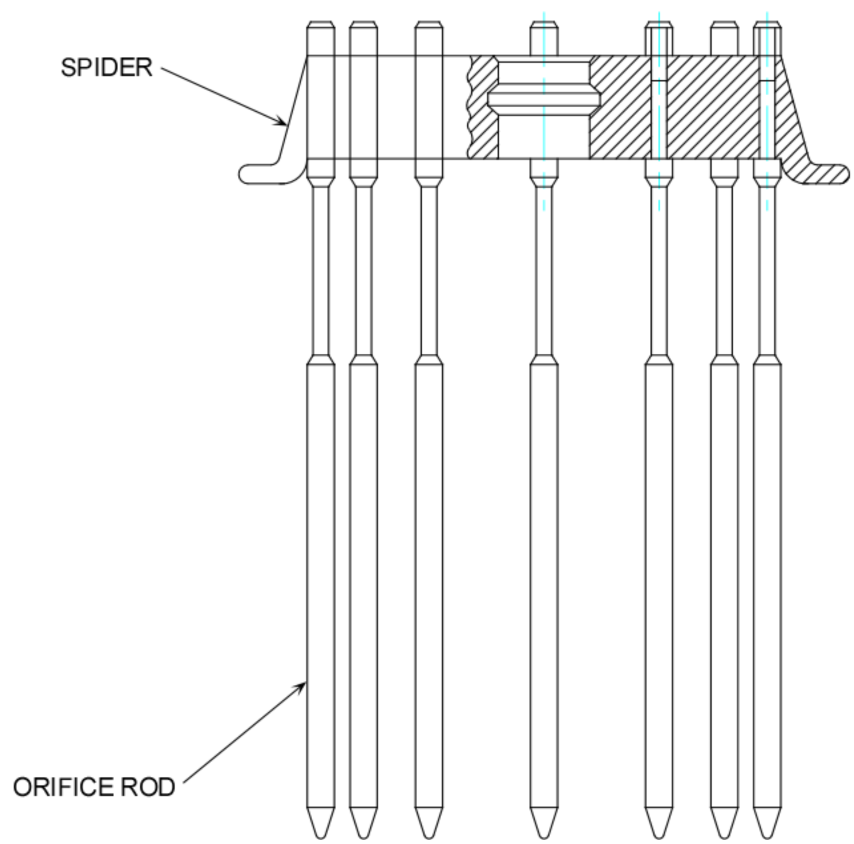

Figure 2.1-12 Orifice Rod Assembly

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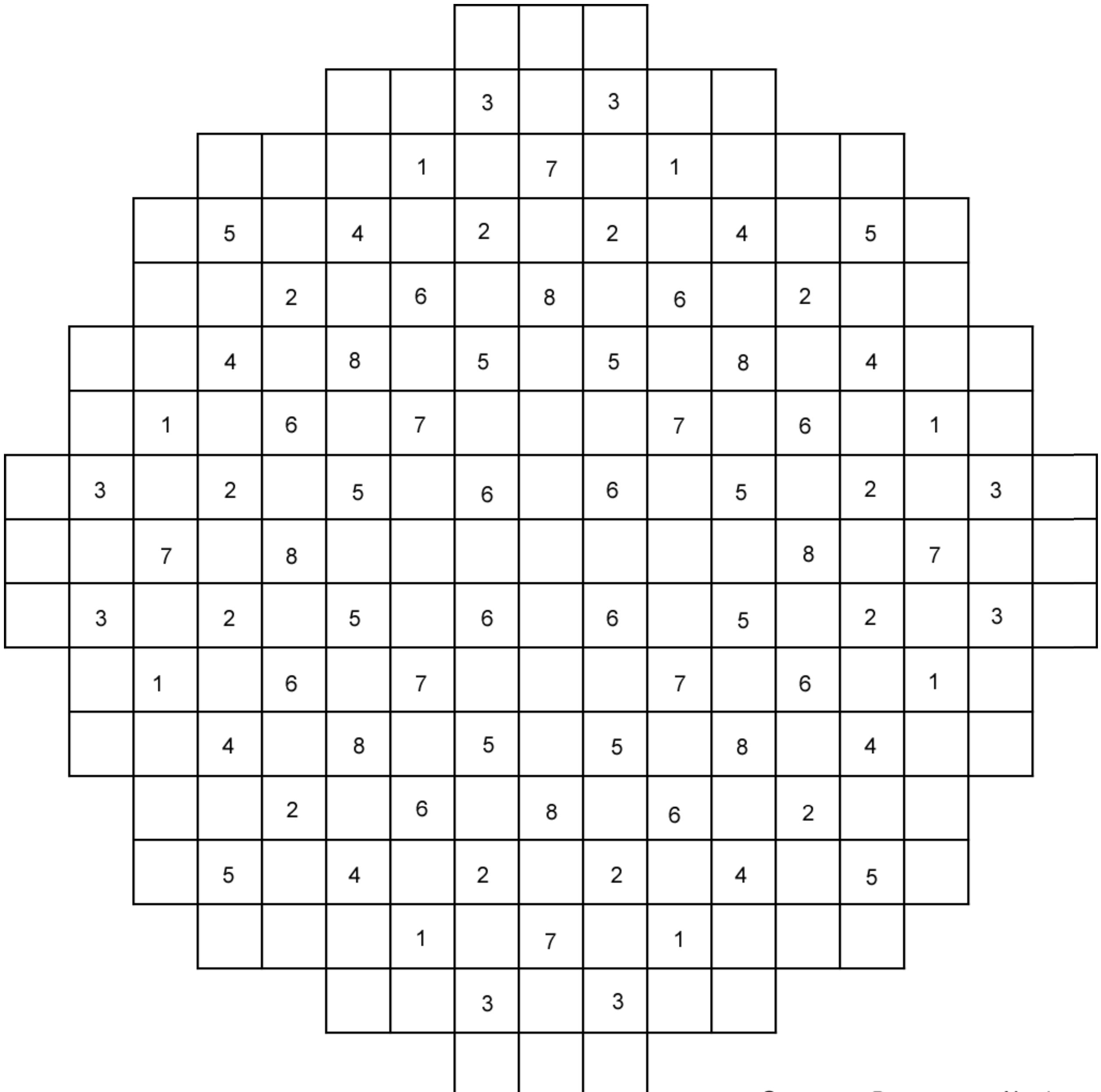

Group	Purpose	Number
1	Safety	8
2	Safety	12
3	Safety	8
4	Safety	8
5	Regulating	12
6	Regulating	12
7	Regulating	8
8	APSR	8
		76

Figure 2.1-13 Control Rod Assembly Locations

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							4	4	4							
					4	4	3	3	3	4	4					
			4	3	3	2	3	1	3	2	3	3	4			
		4	3	3	1	3	1	2	1	3	1	3	3	4		
		3	3	2	2	1	2	1	2	1	2	2	3	3		
	4	3	1	2	1	2	1	2	1	2	1	2	1	3	4	
	4	2	3	1	2	1	2	1	2	1	2	1	3	2	4	
4	3	3	1	2	1	2	1	2	1	2	1	2	1	3	3	4
4	3	1	2	1	2	1	2	2	2	1	2	1	2	1	3	4
4	3	3	1	2	1	2	1	2	1	2	1	2	1	3	3	4
	4	2	3	1	2	1	2	1	2	1	2	1	3	2	4	
	4	3	1	2	1	2	1	2	1	2	1	2	1	3	4	
		3	3	2	2	1	2	1	2	1	2	2	3	3		
		4	3	3	1	3	1	2	1	3	1	3	3	4		
			4	3	3	2	3	1	3	2	3	3	4			
					4	4	3	3	3	4	4					
							4	4	4							

Fuel Region	Weight % U-235
1	2.26
2	2.61
3	3.02
4	3.49

Figure 2.1-14 First-Cycle Core Loading

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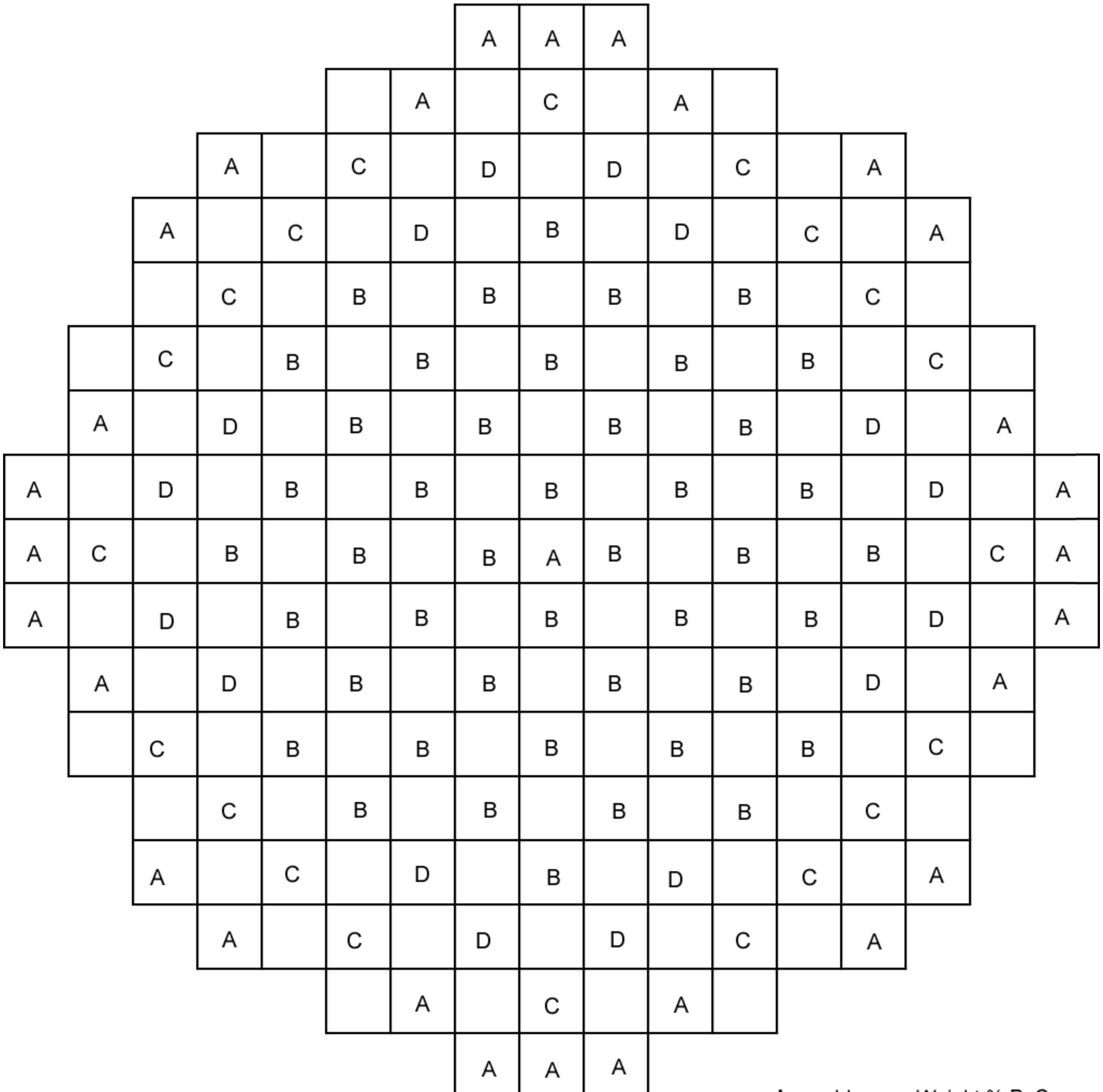

Assembly	Weight % B_4C
A	0.70
B	1.00
C	1.45
D	1.90

Figure 2.1-15 First-Cycle Burnable Poison Assembly Loading

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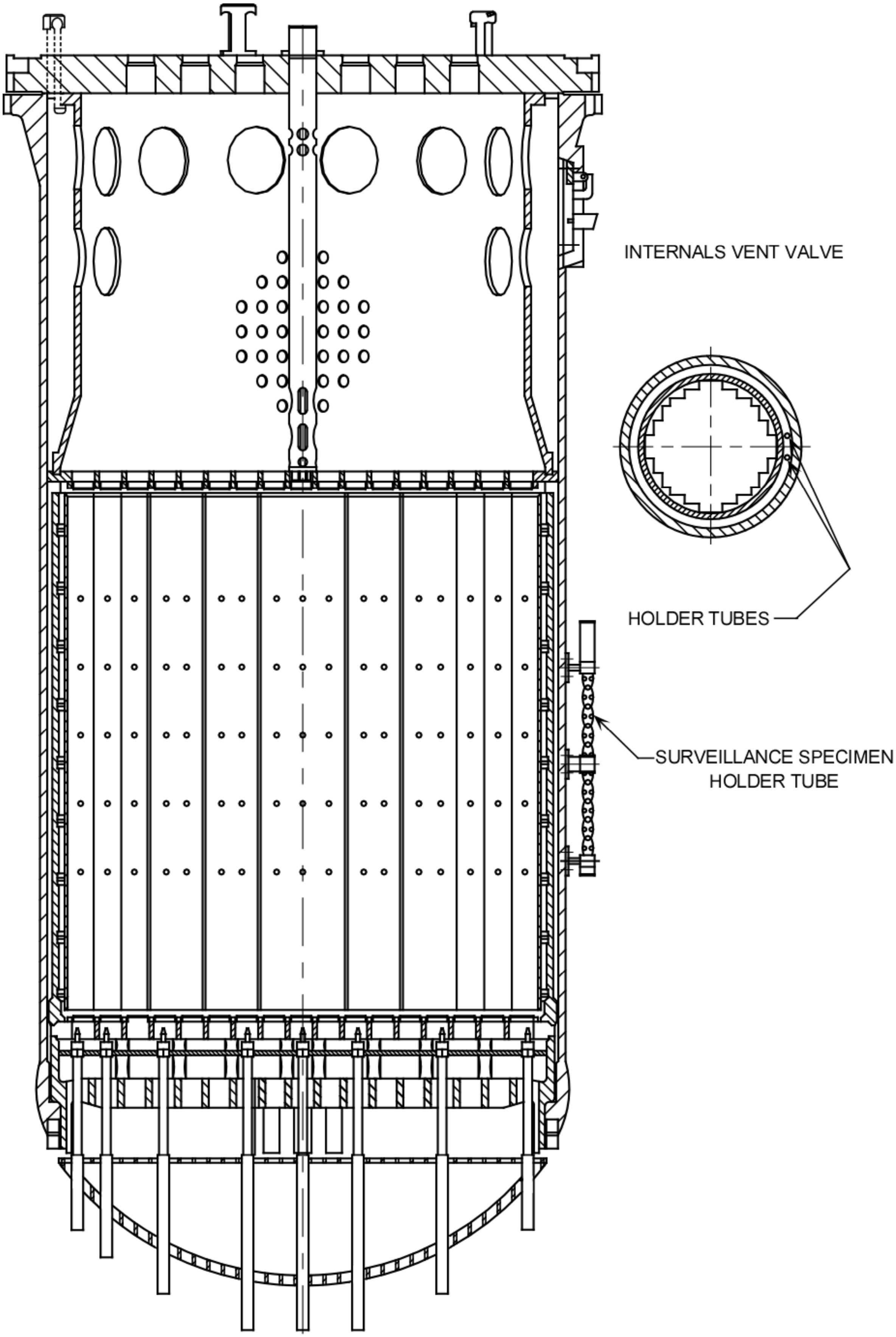

Figure 2.1-16 Core Support Cylinder

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